

VEGETATIVE CHANGES IN A WETLAND IN THE VICINITY OF A WELL FIELD, DADE COUNTY, FLORIDA

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CONTENTS

	Page
Abstract	1
Introduction	1
Purpose and scope	2
Description of study sites	2
Existing information on vegetation	2
Previous studies	2
Present study	5
Methods of vegetation analysis	6
Vegetative changes	10
Difference among sites	10
Effects of shortened hydroperiod	13
Summary and conclusions	14
References cited	15

ILLUSTRATIONS

	Page
Figure	
1. Map of study area	3
2. Photographs of community type H (herbs) showing:	
a. Dense, robust sawgrass along with community type S (shrubs-small trees) in background at site NW, March 1988	8
b. Sparse sawgrass of low stature and other grasses and sedges, with scattered seedlings and saplings of melaleuca at site SW, March 1988	8
3. Photograph of community type S (shrubs-small trees) showing saplings of melaleuca at site SW, March 1988	9
4. Photograph of community type T (trees-forest) showing melaleuca trees along with community type H (herbs) in immediate foreground at site NW, March 1988	9
5. Photograph of community type HS (herbs and shrubs-small trees) showing melaleuca small trees and sawgrass at site NW, March 1988	10
6. Photographs of community type ST (shrubs-small trees and trees) showing:	
a. Willow and bay trees at site NW, March 1988	11
b. Melaleuca saplings and trees at site NW, March 1988	11
7-9. Graphs showing:	
7. Relative frequency of vegetation community types at site NW and site NE, 1978 and 1986 ..	12
8. Relative frequency of vegetation community types at site SW and site SE, 1978 and 1986 ..	12
9. Change in relative frequency of vegetation community types at sites NW, NE, SW, and SE, 1978-86	13

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ABSTRACT

Plant communities present in 1978 and 1986 were analyzed at 250 random points on stereoscopic pairs of aerial photographs for four study sites in the vicinity of the Northwest Well Field in Dade County, Florida. Sites NW and NE lie northwest of the well field beyond the cone of depression. Site SW lies in the outer part of the cone, and site SE lies within the cone of depression. Relative frequency values for several plant types including herbs, shrubs-small trees, and trees were analyzed by the Heterogeneity G-Test to determine heterogeneity among sites in 1978 and 1986.

In 1978, all four sites were dominated by plant communities having herbs, shrubs, or a mixture thereof. The communities at sites NW and NE were similar, and those at SE and SW were somewhat similar. In 1986, sites NW, NE, and SE were dominated by a mixture of shrubs and trees. Only at site SW was the relative frequency of occurrence of herbaceous plants still high. At each site, there was a decrease in herbaceous vegetation and an increase in woody vegetation during this period, with the increase in trees being greatest at site SE.

Time between the start of the well-field operation in May 1983 and the January 1986 photographs was insufficient to allow determination of any direct effects of the well field on the vegetation. Ground-level observations in 1987 and 1988 indicate a trend toward continued increase in dominance of woody plants and a decrease in herbaceous wetland vegetation. Development of a forest of the exotic pest tree melaleuca is occurring at all four sites, but especially at site SE. Vegetative changes between 1978 and 1986 are attributed to an invasion of the exotic species melaleuca, a shortened hydroperiod, and natural succession within the plant communities.

INTRODUCTION

The Everglades in southern Florida, estimated to have once occupied more than 3,600 mi² (Davis, 1943; Egler, 1952), may have been, at one time, the largest marsh or herbaceous wetland in North America (Loveless, 1959b) and the largest single tract of organic soils in the world (Stephens, 1974). However, as a result of efforts to drain parts of The Everglades, which began in the early 1900's (Parker and others, 1955), a considerable area of wetlands has disappeared, and some of the organic soils have been lost as

a result of exposure, fire, and encroachment by agricultural activities, urbanization, and various other activities. Loveless (1959b) estimated that by the 1950's the marsh was only about 2,000 mi². Additional areas of The Everglades, no doubt, have been drained since that time. After about a century of impact by man's activities, most (if not all) of the remaining freshwater wetlands of south Florida is no longer natural (Alexander and Crook, 1973; Alexander and Crook, 1975; Wade and others, 1980).

Many factors affect selection of species, plant vigor, and the character of plant communities, but the most important factors in a wetland, such as The Everglades, are almost always hydrologic conditions. Wade and others (1980) considered reduction in hydroperiod to be the primary threat to all of the freshwater wetland communities of south Florida. McPherson (1973, p. 8) reported that "differences of only a few inches in depth or changes in period of inundation will determine, in time, what plant communities are present" in The Everglades. Many other investigators have reported changes in species composition which have resulted from altered water conditions in The Everglades (Davis, 1943; Loveless, 1959a; Loveless, 1959b; Kolipinski and Higer, 1969; Dineen, 1972; Dineen, 1974; Alexander and Crook, 1973; Alexander and Crook, 1975; Schortemeyer, 1980; Worth, 1983).

The factor that is commonly ranked second in determining the composition and diversity of vegetation in The Everglades is fire. In south Florida, fire is a natural force that can be caused by lightning, which is characteristic of the wet season from late May through October. Over the past several decades, incendiary (arson) fires have been greater in frequency and in area burned than natural fires (Hofstetter, 1973). Although the native species that have prevailed in The Everglades are adapted to natural fire conditions, fires under different conditions, and especially at other times, may cause some degree of stress for them (Daubenmire, 1968; Wade and others, 1980).

Exotic plants are the third greatest threat to natural plant communities of The Everglades. The invasion and dominance of exotic pest plant species—notably melaleuca (*Melaleuca quinquenervia*) and Australian

pine (*Casuarina* spp.)—in almost all of the freshwater wetland plant communities is a problem that is increasing in area and severity. Melaleuca may be better adapted to a wider range of the current conditions in the freshwater wetlands of south Florida than any native species. It has numerous adaptations that not only enable the plant to resist fire damage, but favor its invasion and establishment. Fires within part of the dry season may be particularly conducive to melaleuca invasion (Wade and others, 1980; Hofstetter, in press).

Increasing threats to the remaining wetlands in south Florida result from continued population growth, limited availability of upland sites, increasing demands for water, and needs for flood protection of developments. Wetlands are no longer automatically considered to be wastelands. The intrinsic values of wetlands are becoming increasingly appreciated, and preservation of wetlands is beginning to prevail (Hofstetter, 1983).

The possible effects that the operations at the Northwest Well Field may have on the vegetation of adjacent wetlands of the historic Everglades west of Miami is of concern to water-management officials and others. The pumping operation began in May 1983 within an area of wetland that historically was characterized by sawgrass marsh and tree islands. The 1987 vegetation of herbs, shrubs, and trees reflects a shorter hydroperiod than sawgrass, although sawgrass and more hydric species still exist in some parts of the area. The existing natural tree islands have been altered by fires and contain appreciable exotic vegetation. Concern has been raised as to what role the lowering of the water table by as much as 6 feet (Klein, 1986) and the resulting shortened hydroperiod caused by operation of the well field may have had in these observed vegetational changes (Davis, 1943; Craighead, 1971; McPherson, 1973; Alexander and Crook, 1973; Alexander and Crook, 1975).

Purpose and Scope

The purpose of this report is to describe: (1) the vegetation in the area before operation of the well field began; (2) any change in vegetation occurring in response to regional changes in hydrologic conditions, independent of the operation of the well field; (3) the vegetation in the area at the end of 3 years of well-field operation; and (4) to the extent possible, identify the effects of well-field operation on vegetation in the area. Data collected during this investigation will also serve as a baseline for assessing future changes in vegetation.

Description of Study Sites

The study area is bounded on the northeast by the Miami Canal, on the east by the Snapper Creek Canal

extension, on the south by the Tamiami Canal, and on the west and northwest by Levee L-30 Canal (fig. 1). The Levee L-30 Canal, Levee 30, and Conservation Area 3B lie to the west. The Dade-Broward Levee lies north-south through the entire area, 2 miles east of the western boundary. The Pennsuco Canal lies west-east about 3.5 miles south of the northern limit of the study area. Several small canals and numerous artificial lakes, which resulted from rock-mining activities, exist in the eastern part of the area.

Four vegetation study sites, identified as northwest (NW), northeast (NE), southwest (SW), and southeast (SE), were selected for this investigation (fig. 1). Sites NW and NE, which lie outside the present cone of depression (Klein, 1986), are used to assess ongoing regional vegetative changes within the area. Site SE lies immediately west of the well field and is within the cone of depression, whereas site SW lies in the outer western part of the cone. The two southern sites, therefore, serve to determine any additional vegetational changes affected by the well-field operation. The long-term record of hydrologic data since June 1959, at two U.S. Geological Survey observation wells (G-972, site NW; G-976, site SE) facilitates comparisons in vegetational trends with hydroperiod changes within the region.

Existing Information on Vegetation

No quantitative study of vegetation had previously been made of the entire area, but several descriptions and interpretations of vegetation exist for parts of it. Summaries of these studies are discussed in the following sections.

Previous Studies

In December 1971, R.H. Hofstetter and T.R. Alexander (University of Miami, written commun., 1972) traversed more than 9 miles of the northern third of the study area to determine general vegetative conditions as part of a site selection process for a possible new airport. On the basis of this field study and interpretation of aerial photographs, they characterized this area as an open graminoid (grasses and sedges) wetland, with numerous widely separated discrete stands of mature melaleuca as well as scattered trees and saplings. Melaleuca was estimated to have occupied less than 10 percent of the area.

Alexander and Crook (1975) made a detailed investigation of plant communities in the mile square area of section 16, in Township 52 south (T52S), Range 39 east (R39E) in the northwest part of the current study area (fig. 1). There, they determined vegetation conditions by analysis of aerial photographs taken in

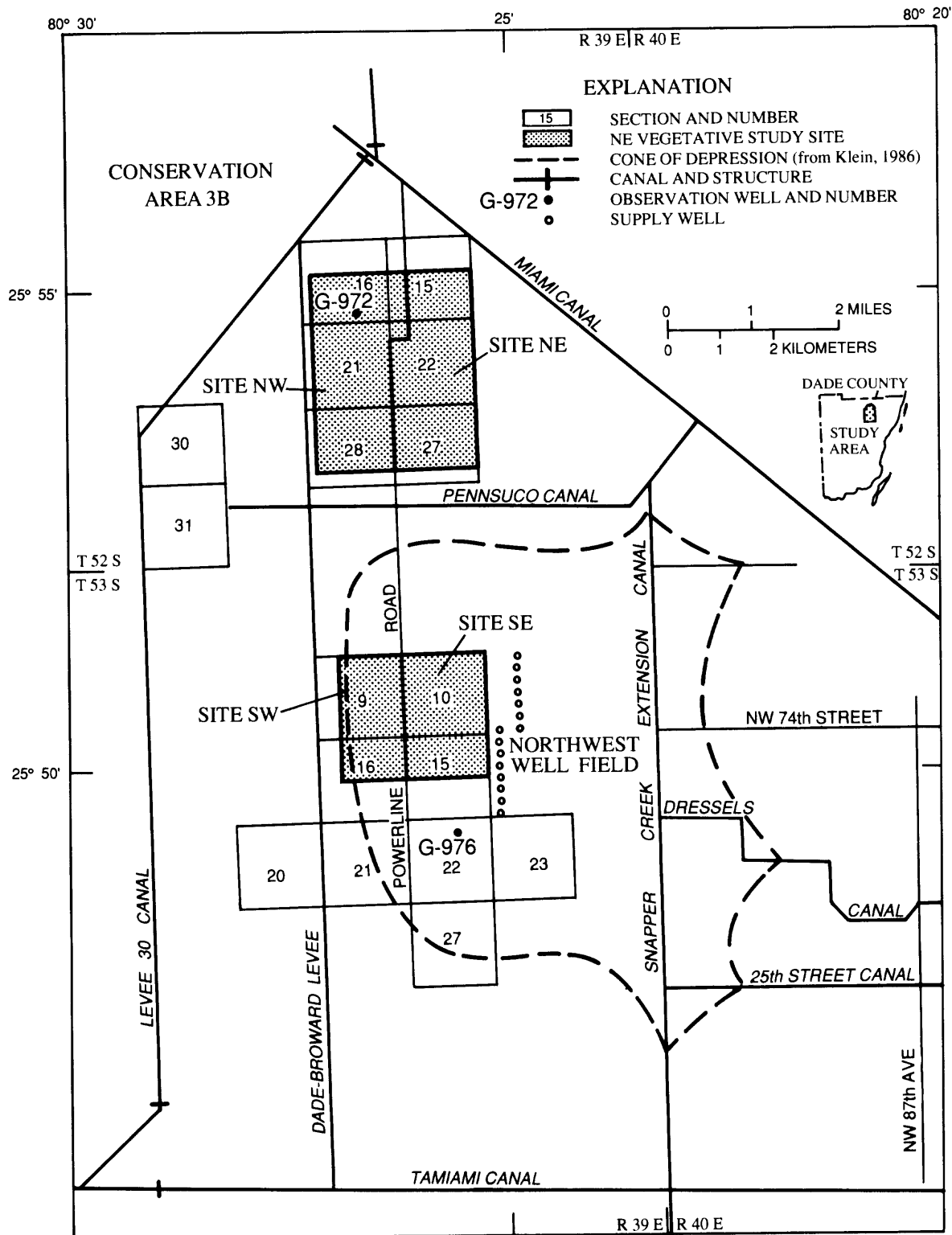


Figure 1. — Study area.

December 1970 and ground studies in the early 1970's. Alexander and Crook (1975, p. 389) describe the vegetation that was present in 1973 in section 16 which they referred to as quadrat 64 as:

"Composed of a variable prairie trending from predominantly mesic grasses and shrubs in the northwest to a mosaic of sawgrass and beak rush over much of the rest of the quadrat. This lower prairie also contains isolated mesic species, as well as strands of dense, healthy sawgrass. Small associations of primrose willow, willow and wax myrtle form the only native tree islands. Cajeput (melaleuca) has saturated the quadrat. It is found in both high and low prairies, as open associations of various aged trees, invading willow heads, and as dense, expanding, almost pure stands or heads in which the only replacement seen was young cajeput."

Alexander and Crook (1975, p. 394) determined general vegetational changes that had occurred over the preceding 30 years by interpreting photographs taken in May 1940. Their interpretation of changes between 1940 and the early 1970's follows:

"It is possible that there has been a mesic shift in the native prairie communities as a result of diking and drainage, but there is little photographic or onsite evidence to support this, other than the existence of small shrubs and comparison with impounded prairie (quadrat 65; immediately west of quadrat 64 in Conservation Area 3B). Photography of both years is poor, and the appearance or disappearance of community margins between the two models is not considered significant, except for the development of cajeput heads. Although it is impossible to date the cajeput invasion, the appearance of the trees and the development of a major head between 1940 and the present indicate a relatively recent, ongoing phenomenon. Its spread may be fire assisted, as several locations showed evidence of fire, with minimal effects on cajeput. Inside the major head, dense seedling populations were growing in peat fire scars."

General information on vegetation is available from reports by the Dade County Department of Environmental Resources Management (DERM) made in response to requests for permits of certain activities in the study area. These surveys typically include a brief descriptive narrative of plant

communities, a list of common flora, and a general statement of environmental conditions. Following is a synopsis of the vegetation from some of these reports closest to the study sites.

In sections 30 and 31 (T52S, R39E), which are west of the Dade-Broward Levee (fig. 1), the vegetation was described by the Dade County Department of Environmental Resources Management (1979b) to be "viable wetlands habitat dominated by two species of graminoids, *Cladium jamaicensis* (sawgrass) and - *Eleocharis* sp. (spike rush)" with varied impact of melaleuca. Another site within these two sections of land, again described by the Dade County Department of Environmental Resources Management (1979d), was found:

"...to consist primarily of a wetland graminoid community dominated by sawgrass (*Cladium jamaicensis*). A variety of other wetland graminoids were interspersed with the sawgrass. These include spike rush (*Eleocharis cellulosa*), beak rush (*Rhynchospora* sp.), and maidencane (*Panicum hemitomon*)."

The southern part of this site had "undergone invasion by the exotic tree species *Melaleuca quinquenervia*," which was present as "dense stands of mature individuals in some areas to sparse stands of seedlings and saplings in other areas." Also present was a tree island containing "a variety of hardwood species and understory vegetation including strangler fig (*Ficus aurea*), red bay (*Persea borbonia*), willow (*Salix caroliniana*), Brazilian pepper (*Schinus terebinthifolius*) and leather fern (*Acrostichum danaeae-folium*)."

The vegetation on property within the northeast corner of section 20 (T53S, R39E) (fig. 1), in December 1978 and January 1979, was described as *Cladium/Eleocharis* (sawgrass-spike rush) wetlands prairie, with a few scattered melaleuca trees. Section 21 contained a wetlands prairie with melaleuca covering about half of the area; and a hardwood hammock containing *Persea borbonia* (red bay), *Ficus aurea* (strangler fig), *Ilex cassine* (dahoon holly), and *Myrsine quianensis* (myrsine), with a fern understory of *Acrostichum danaeae-folium* and *Nephrolepis* sp. (Dade County Department of Environmental Resources Management, 1979a).

In May 1979, sections 22 and 23 (T53S, R39E) were determined by the Dade County Department of Environmental Resources Management (1979c) to be:

"Wetlands community undergoing extensive transition to upland community dominated by an exotic tree species, *Melaleuca quinquenervia*... with dense forests of mature trees covering 50 to 60 percent of the project site. The remainder consists of vestigial wetland graminoid communities (sawgrass-spike rush)."

Part of section 22 is included in site SE.

The vegetation in section 27 (T53S, R39E) is described in Connell, Metcalf, and Eddy (1981, p. 3-1) as "historical wetlands which are currently in a phase of succession to transitional exotic-dominated wetlands." Specifically it was wet prairie dominated by sawgrass (*Cladium jamaicensis*), with beak rush (*Rhynchospora* sp.) and maidencane (*Panicum hemitomon*) common. "Melaleuca is common throughout the site; seedlings and saplings of melaleuca are common in the wet prairie community and become dense around the edges of melaleuca heads (stands)." Melaleuca occupied 27 percent of the 550 acres of the property.

Certain existing canals are being improved, and new canals are being dug in the northern part of the study area to carry additional surface water to the eastern side of the Northwest Well Field. The Northwest Well Field canal improvement project location, given by the Dade County Department of Resources Management (1985), is described as:

"An area of stressed wetlands in which the exotic tree species, *Melaleuca quinquenervia*, has displaced native wetland species to varying degrees. Although the area is still subject to extended hydroperiods lasting 5 months during an average year, there has been a substantial amount of hydrologic stress due to the effects of surrounding roads, levees and canals. The hydrologic stress has been exacerbated in recent years due to the draw-down of water levels from the Dade County Northwest Well Field. The spread of melaleuca in the area has, in part, been a function of this hydrologic stress. Due to the recent drought, the area has also been subject to intensive wildfires which have destroyed large stands of mature melaleuca and resulted in the presence of large even-aged stands of regenerating melaleuca. Moreover there has been a pattern of regularly destructive wildfires in the area over the past several years which has served to promote the spread of melaleuca throughout the area."

Plant communities along the proposed route of this project, as discussed by the Dade County Department of Environmental Resources Management (1985), include:

"Shallow water areas (with cattail *Typha* spp., alligator flag *Thalia geniculata*, and arrowhead *Sagittaria lanceolata*), marsh (predominantly [sawgrass] *Cladium jamaicensis* and a variety of other emergent and hydric herbaceous species, grasses and sedges), flats (a variety of emergent species, including [spike rush] *Eleocharis cellulosa*, [maidencane grass] *Panicum hemitomon*, *Cladium jamaicensis*, and [beak rush] *Rhynchospora* spp.), as well as melaleuca forest, spoil bank-scrub, spoil bank-forested and aquatic communities of the canals."

The national wetlands inventory maps (Pennsuco, Fla., and Hialeah, SW, Fla.) of the U.S. Fish and Wildlife Service (written commun., 1989) in St. Petersburg, Fla., identify most of the area as palustrine wetland (P) with either seasonal (C) or temporary (A) water regime. The most common vegetation type is PEM5C (emergent, narrow-leaved persistent). Other community types present include PFO3A (forested, broad-leaved evergreen), PSS3C (scrub-shrub, broad-leaved evergreen), and mixtures of these—PS83/EM5A&C (a mix of scrub-shrub, broad-leaved evergreen and emergent, narrow-leaved persistent) and PF03/EM5A (a mix of forested, broad-leaved evergreen and emergent, narrow-leaved persistent).

Present Study

When the present study began in late March 1987, site NW was a wetland with standing water in many areas and extensive stands of sawgrass, some more than 7 feet tall. Wetter sites contained cattail (*Typha* sp.), spike rush (*Eleocharis* sp.), arrowhead (*Sagittaria* sp.), and alligator lily (*Crinum americanum*). Melaleuca was common throughout the area as dense stands and scattered individuals of mature trees, some estimated to be more than 60 feet high, with younger trees and saplings locally abundant within the sawgrass. Scattered within the area were plants of the native woody species wax myrtle (*Myrica cerifera*) and lesser numbers of willow (*Salix caroliniana*). More mesic species of herbs and graminoids were generally absent in the undisturbed areas between U.S. Geological Survey well G-972 and the north-south powerline road (fig. 1). The remnants of a large tree island, extending from sites NW to NE, were heavily invaded by melaleuca.

In March 1987, site SE had no standing water, and surficial sediments were dusty dry. The surface crust of muck and marl occasionally broke under one's weight. Patches almost devoid of living macrophytes were common. This site was dominated by melaleuca as dense stands and scattered individuals of tall trees and saplings. Patches and scattered individuals of healthy wax myrtle were common. Sawgrass was present as scattered plants of low stature, but more mesic graminoids and herbs were more abundant than sawgrass. Scattered dead culms (plants) of sawgrass were common. Parts of this site were burned in spring 1985. Depressions up to 3 feet deep in the muck in some melaleuca stands indicate the presence of earlier ground fires.

In most of the eastern half of site SW, surface sediments were dry. Graminoid communities were more extensive than at site SE, and sawgrass was the dominant graminoid, but the plants were small in stature and generally not dense, except in scattered, wetter depressions. Mesic graminoids that were common at site SE were not common here. Also, there were large patches of sediment almost devoid of macrophytes. Melaleuca was abundant as scattered, discrete, dense stands of larger trees. Seedlings and saplings, although present, were generally more scattered and less abundant than in site SE. Native woody plants were less common than in site SE.

METHODS OF VEGETATION ANALYSIS

Remote-sensing techniques of aerial-photograph analysis were used to evaluate major vegetative changes. The quality of available photographs and the experience of the interpreter determine the upper limits of vegetative detail.

Examination of aerial photographs for the area and times of interest resulted in selection of photographs for periods before and after the well field was placed in operation as follows:

- Conditions before well-field operation. — Photographs 7917 LN69-RN1, December 13, 1978, 1:25,000 (9-inch square, false color infrared transparencies), numbers 67 and 68 for sites SW and SE (1978) and numbers 64 and 65 for sites NW and NE (1978), taken for the U.S. Environmental Protection Agency and borrowed from DERM. No suitable photographs were found for the sites at a time immediately before pumping.

- Conditions after well-field pumping started. — Photographs 366, January 31, 1986 (9-inch square, black and white negatives), numbers 252 and 254 for sites SW and SE (1986) and numbers 231 and 233 for sites NW and NE (1986), taken by Continental Aerial Surveys¹, Bartow, Fla., for the South Florida Water Management District and borrowed from Beadman and Associates, Miami.

The stereoscopic image for sites NW and NE encompasses most of sections 15, 16, 21, and 22 and the upper part of sections 27 and 28 (T52S, R39E); and for sites SW and SE all of sections 15 and 16, most of sections 9 and 10, and the upper part of sections 21 and 22 (T53S, R39E) (fig. 1).

Several quantitative approaches to interpretation of vegetation were evaluated. Mapping communities through interpretation of aerial photographs was discarded because many of the boundaries between communities were broad and poorly defined; thus, line boundaries would only be arbitrary.

The random-point method for sampling vegetation (Thorley, 1975) was selected. This technique assumes that analysis of vegetation in replicate sets of an adequate number of random points of the same area will yield similar results.

Aldrich (1968), given in Thorley (1975), stated that the point-sampling method for forest inventories is relatively fast and accurate with errors in acreage estimates of less than 1 percent. According to Langley (1962), also given in Thorley (1975), point sampling is preferred to complete delineation because: (1) a set of values is generated from which a proper random subset may be selected for ground truthing, (2) it is easier and more accurate to identify the community at the point than to assign a community identification to a larger area, (3) the frequency data facilitate critical statistical analyses, and (4) it is faster and less expensive than interpreting and calculating the area of communities. The random-point sampling method had also been used successfully in a determination of the relative area of plant communities in the East Everglades by Hofstetter and Hilsenbeck (1979).

The procedure involves mounting, rectifying, and interpreting each stereoscopic pair of aerial photographs using a Kern PG-2 stereo plotter with a magnification value of 4, the smaller "floating mark," the 0.55 disc, and a sapphire point in the pantograph.

¹Use of firm, brand, and trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

For this study, the mylar grid of 1,225 cells was positioned with its bottom along the south side of the stereoscopic image, and the cross hair (in the middle of the grid) was positioned in the middle of the road at power transmission tower 32 for sites NW and NE and at tower 9 for sites SW and SE (fig. 1). The middle line of the grid between columns 17 and 18 was placed in the middle of the north-south powerline road, which separates SW from SE. Each photographic pair included both the SW and SE sites. A single set of random numbers was used to locate the sampling points for each site.

The general vegetation at 250 random points within each site was determined by visual interpretation using the stereoscopic viewer. This sampling represented more than 40 percent of the maximum possible number of points for that part of the grid.

The stereoscopic image (determined by the amount of photographic overlap) is a rectangle with the shorter dimension along the flight path. The flight paths used on the two photographic dates were perpendicular to one another, and the stereoscopic-image rectangles have different dimensions. Therefore, only sampling points that fall within the inclusive smaller rectangle common to both stereoscopic pairs for each site are included for analysis of vegetational changes over time.

Stereoscopic photographs were interpreted in July and again in September 1987, and the results were compared. Replicate attempts to locate the identical points on the stereoscopic pair during reinterpretation proved futile.

The 1978 color photographs are easier to interpret because they have better clarity and stereoscopic imagery than the 1986 prints, which have parallax in some areas. Values for sampling points for both sampling dates were discarded where parallax or other conditions made it difficult to identify the exact point on either set of photographs.

Community identification and designation were modified during several analyses. While communities were identified and recorded in greater detail than reported here, they were combined into five general types, each characterized by the following vegetation:

- H (herbs) — A community dominated by herbaceous plants, most commonly graminoids; that is, grasses and sedges (fig. 2a-b).
- S (shrubs-small trees). — A community dominated by shrubs and/or small trees, most commonly *Melaleuca quinquenervia* (fig. 3).

- T (trees-forest). — A community dominated by tall and usually dense trees, most commonly *Melaleuca quinquenervia* (fig. 4).
- HS (herbs and shrubs-small trees). — A mixed community having components of, or transitional between, H and S (fig. 5).
- ST (shrubs-small trees and trees). — A mixed community having components of, or transitional between, S and T (fig. 6a-b).

These vegetation types were selected because they are easily identified on black-and-white aerial photographs of reasonable quality and scale by any individual with some previous interpretive or ground-truthing experiences, and yet are appropriate to assess changes that may occur after several years as a result of a lowering of the water table in wetlands.

In the analysis and interpretation of the aerial photographs, the plant community under the pointer was recorded for each set of random coordinates, providing a frequency record of community types. The total frequency data for each site at each time was then compared by means of the G_H-Test, the Heterogeneity (Interactive) G-Test (Sokal and Rohlf, 1981a; 1981b), using the micro computer program "RXC" (row-by-column test of independence in contingency tables) of BIOM-PC (Rohlf, 1984; 1988). This program determines the extent of similarity of the sites based on the ratio of frequency values for each community type within each site for each time. An alpha value of 0.05 was selected to make the criterion for heterogeneity (nonhomogeneity) liberal.

Blue-line copies of photographs taken in February 1987 for tax assessment purposes by Dade County were used for ground truthing. The study area was examined on foot, and field conditions were compared to photographic images on Dade County Tax Photographs and draft rectified maps (panel numbers 3-1 and 5-1) prepared by Beadman and Associates in 1987 for the South Florida Water Management District. The latter set of maps was prepared from the 1986 aerial photographs that are used in this study.

The random point-sampling method proved efficient in time and effort and yielded replicable and statistically analyzable data for this study. Although boundaries between communities are diffuse because of the small size of the point, errors in replicated interpretations of vegetation types are uncommon. An error of less than 10 percent resulted for replicates that involved the entire process of mounting photography in the plotter, aligning the grid, and interpreting the image.



Figure 2a. — Community type H (herbs) showing dense, robust sawgrass along with community type S (shrubs-small trees) in background at site NW, March 1988.



Figure 2b. — Community type H (herbs) showing sparse sawgrass of low stature and other grasses and sedges, with scattered seedlings and saplings of melaleuca at site SW, March 1988.



Figure 3.— Community type S (shrubs-small trees) showing saplings of melaleuca at site SW, March 1988.



Figure 4.— Community type T (trees-forest) showing melaleuca trees along with community type H (herbs) in immediate foreground at site NW, March 1988.



Figure 5. — Community type HS (herbs and shrubs-small trees) showing melaleuca small trees and sawgrass at site NW, March 1988.

VEGETATIVE CHANGES

Difference Among Sites

Relative frequency values for each of the vegetation types by site and date are presented in figures 7 to 9. Vegetational conditions in 1978 and 1986 for each site (NW, NE, SW, SE) are presented first, followed by an analysis of the changes that have occurred over the 8-year interval. The four sites are then compared with one another for similarities and patterns of change of vegetation.

At site NW in 1978, 68 percent of the sampling points were dominated by combined herbaceous (H, 37 percent) and herb-shrub mixed (HS, 31 percent) vegetation (fig. 7). Of the woody-plant communities, shrubs-small trees (S) were most abundant at 20 percent. In 1986, however, the community types at site NW were predominantly woody, with 35 percent trees (T), 29 percent shrubs-small trees (S), and 4 percent shrubs-trees (ST) (fig. 7). The H and HS communities combined had a reduction in relative frequency of 36 percent during the period 1978 to 1986 (fig. 9).

At site NE in 1978, there were almost equal proportions of HS, H, and S communities with relative

frequencies of 32, 27, and 23 percent, respectively (fig. 7). Community T existed at less than 10 percent of the sampling points. In 1986, 41 percent of the sampling points were characterized by trees (T), and the combined relative frequency of the herbaceous communities (H, HS) was only 28 percent (fig. 7).

Site SW in 1978 had predominantly herbaceous vegetation, with relative frequency values of 65 percent for H and 19 percent for HS (fig. 8). Other relative frequencies were S, 14 percent and T, 2 percent. In 1986, the combined relative frequency of herbaceous communities (H, HS) was 23 percent lower than in 1978 but still was greater than 60 percent (fig. 8). The relative frequency for T was still low, less than 6 percent. Community S at site SW showed the greatest gain (15 percent) in relative frequency from 1978 to 1986. The gain in community type S was greater at site SW than at any other site (fig. 9). Field observations in 1987 revealed that moderately dense stands of melaleuca saplings and small trees represent much of this S-type vegetation. Most of these plants are more than 3 years old, but probably less than 10 years old. Although the relative frequency of the forest community (T) in 1978 was only 2 percent, the trees were

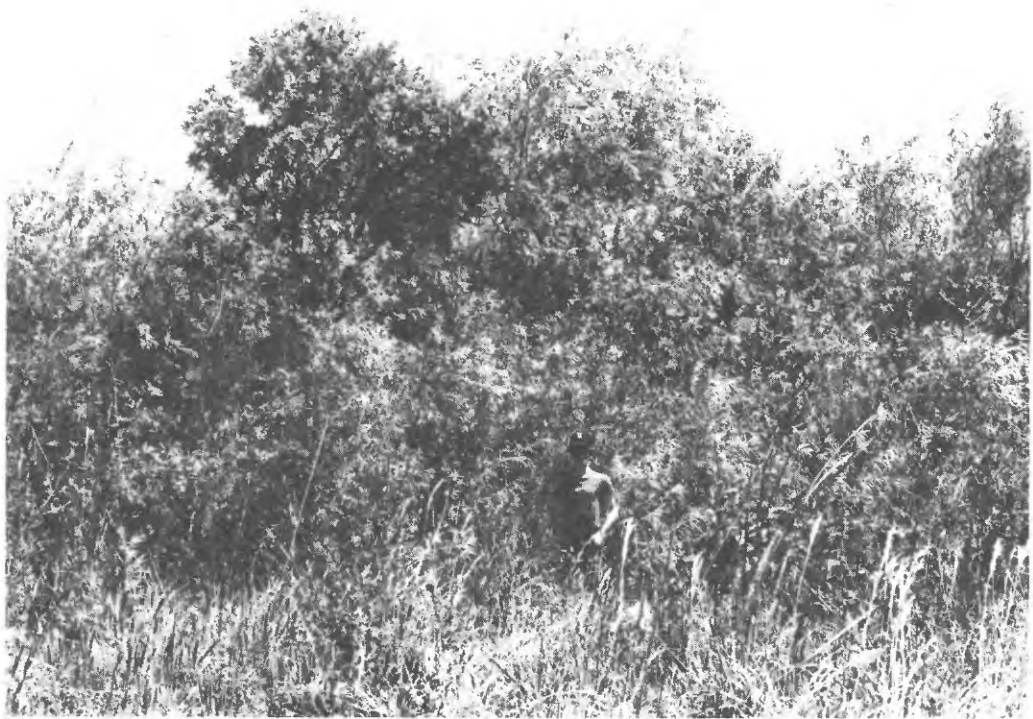


Figure 6a. — Community type ST (shrubs-small trees and trees) showing willow and bay trees at site NW, March 1988.



Figure 6b. — Community type ST (shrubs-small trees and trees) showing melaleuca saplings and trees at site NW, March 1988.

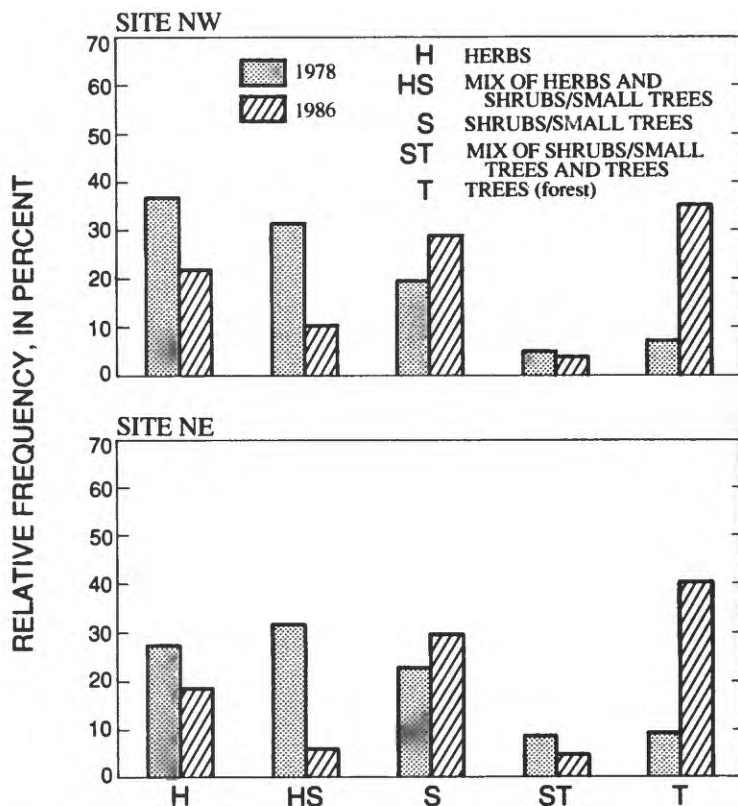


Figure 7.—Relative frequency of vegetation community types at site NW and site NE, 1978 and 1986.

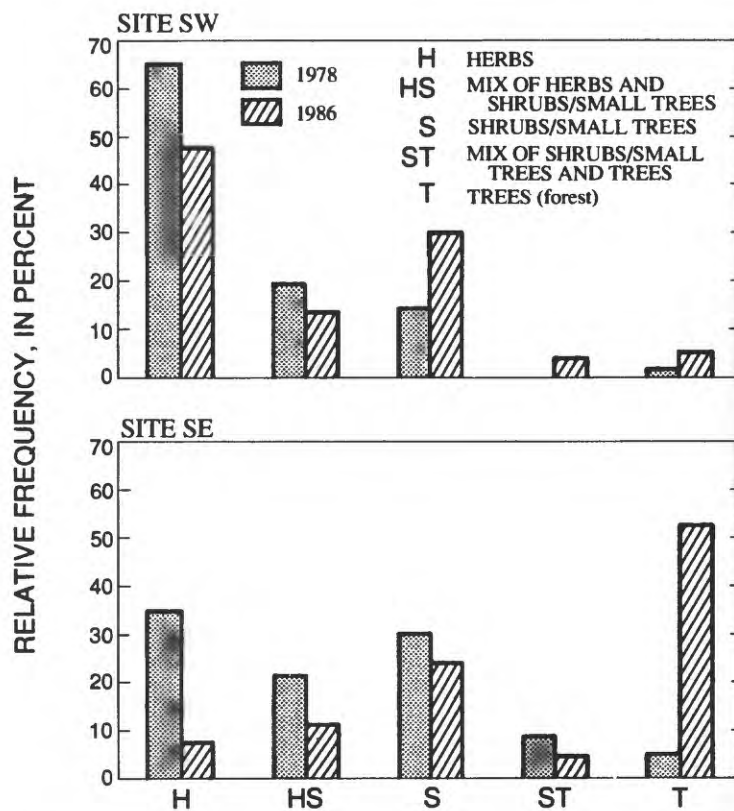


Figure 8.—Relative frequency of vegetation community types at site SW and site SE, 1978 and 1986.

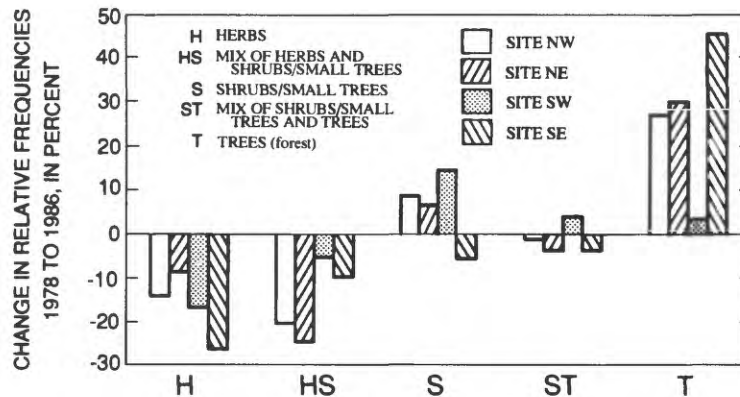


Figure 9.— Change in relative frequency of vegetation community types at sites NW, NE, SW, and SE, 1978-86.

probably mostly mature melaleuca, providing a seed source for future melaleuca forests.

Site SE in 1978 had a high relative frequency of 30 percent for the vegetation type S, second only to community H with 34 percent (fig. 8). The combined relative frequency of ST and T was also high at 14 percent. Communities dominated by woody plants (S, ST, T) had a combined relative frequency of 44 percent, the highest of any site. In 1986, the relative frequency of communities dominated by woody plants had increased to 81 percent, with T alone having a relative frequency of 53 percent (fig. 8). The relative frequency values of all other communities were lower than the 1978 values (fig. 9). The development of forests at this site was primarily the result of melaleuca expansion since 1978. Seedlings and scattered saplings could be abundant in herbaceous vegetation and escape detection by the remote sensing methods. Eight years is adequate time for melaleuca seeds to germinate and produce "saplings" 10 feet tall (Meskimen, 1962). The development of the dense stand of trees at site SE was probably underway before the well field began operation. It is too early to determine what additional effects, if any, the well field will have on vegetational changes there.

For every site, the vegetation in 1986 is significantly different from that in 1978, indicating that appreciable changes in vegetation have occurred throughout the study area. The following comparisons of vegetation among the sites and over time are based on ratios of relative frequency values for each of the five community types as assessed by the Heterogeneity G-Test.

The vegetation at site NW was similar ($0.500 > G_H > 0.100$) to that at site NE in both 1978 and 1986. The plant communities at both sites changed significantly during this period, but in the same fashion. Uniform changes in vegetation at these sites indicate that the vegetational changes may be in response to a regional change in environmental factors or to some change that occurred prior to 1978. Sites NW and NE are outside the current cone of depression and appear to be suitable for assessing changes that may be occurring independently of the well-field pumping.

The vegetation at site SE was different from that at site SW in both 1978 and 1986, but the vegetation at site SW in 1986 was relatively similar ($0.100 > G_H > 0.050$) to that at site SE in 1978, suggesting that conditions at site SW may be tracking those at site SE with a time lag.

Effects of Shortened Hydroperiod

Operation of the well field, which began in May 1983, lowered the water table and shortened the hydroperiod in the vicinity of the well field. This may have caused drought stress on the hydric plants and may have favored the establishment of more mesic and xeric plants. Phenological changes may have taken place with some species, thus, altering their competitive ability. Perennial plants dominate this area. Established perennial plants generally can tolerate years of detrimental conditions before showing visible signs of stress or dying. Species favored by shortened hydroperiod and lower soil moisture could respond with increased growth or reproductive activity, and

more mesic species could invade and dominate the area. It is unlikely, however, that after only 2 or 3 years these changes would be detectable on aerial photographs of the type used. The expected detectable changes in response to the lowered water table in a south Florida wetland will likely be a reduction in herbaceous vegetation and an increase in the coverage and development of woody species (Davis, 1943; Loveless, 1959a; Alexander and Crook, 1973; Alexander and Crook, 1975; McPherson, 1973). Such changes, if they occur, may be detectable with the methods used in this study after 8 or 10 years.

The shortened hydroperiod may promote the spread and development of melaleuca in the wetter parts of this area. Although melaleuca can invade wetlands with long but not continuous hydroperiods, the probability of annual establishment increases with shorter hydroperiods of 2 or 3 months (Meskimen, 1962). A hydroperiod may also be too short and the soil moisture too low for melaleuca seedling establishment (Myers, 1975; 1983). The shorter hydroperiod and reduced water depths will increase the probability of extensive natural fires and may permit greater human activity, and therefore, increased probability of fires caused by man (Hofstetter, 1973; Hofstetter and Parsons, 1975; Wade and others, 1980). Because melaleuca survives and is actually promoted by fire, especially in the dry season, its spread can be expected. A dense forest of melaleuca may be anticipated in this region as well as in many other areas of south Florida.

During field studies at site SE, extensive patches of melaleuca saplings and trees generally less than 25 feet tall showed signs of recent and current stress. Some melaleuca plants were dead, but still retained most of their leaves. Some had only a few living branches with leaves; others had only basal sprouts. Where young shoots and leaves were present, many were wilted. On some plants, both severely wilted and apparently healthy shoots and leaves were present. A few of the plants showed repeated patterns of dieback, then regrowth, indicating alternating periods of favorable and unfavorable growth conditions. This condition was not observed in larger trees and did not occur with this size class elsewhere, even where there had been recent fires. Part of this area burned late in the dry season in 1985. The limits of the 1985 fire are not exactly known, but the remains of surficial charring of the bark suggest that melaleuca showing this stressed condition may occur predominantly in the area of this burn. Normally melaleuca of this age class are pruned by fire, but recover quickly with new growth, and are not permanently harmed by surface fires (Meskimen, 1962; Wade and others, 1980). Plants of similar size

that were also burned in 1985, but which were growing among denser, taller trees, did not show this stressed condition. The stressed condition of melaleuca has not been reported elsewhere. Wax myrtle bushes, which were growing among the stressed melaleuca, appeared healthy with a fresh flush of new shoots and leaves.

It is hypothesized that just prior to well-field operation there were melaleuca of all age classes growing normally at this site. When the wellfield began operation, it rapidly lowered the water table beyond the reach of the root systems of some melaleuca, especially younger ones with less well-developed root systems. These younger plants, which had been growing under more favorable soil moisture conditions, suffered drought stress, and wilted (some dying). This condition would be most severe in the latter part of the dry season when soils are dry and rains are infrequent. With a rain, soil moistures increased to a level favorable to these plants (of which a few recovered with renewed growth) only to experience increasing drought stress until the next rain. The absence of seedlings in this area suggests that the plants probably died as a result of this drought stress. A major weakness of melaleuca is that their seedlings are intolerant of low soil moistures (Meskimen, 1962; Myers, 1975). The 1985 fire burned the leaves and smaller branches off these saplings. For those plants that resprouted, high evapotranspiration from the new leaves and shoots caused additional drought stress on the plants. Larger trees did not show this stress because they are probably growing in pockets of deeper organic sediments with a higher water content, and their branching is reduced, producing a lower shoot-to-root ratio in dense stands where rates of evapotranspiration are also lower than in the open. This condition in melaleuca here is being studied.

SUMMARY AND CONCLUSIONS

The vegetation type with the greatest relative frequency in 1978 at all sites was herbaceous (H and HS) with values ranging from 56 percent at site SE to 84 percent at site SW. The relative frequency of trees-forest (T) ranged from 2 percent at site SW to 9 percent at site NE. The 1978 vegetation at the two northern sites (NW and NE) was similar. The 1978 vegetation at sites SW and SE was different from that of the other sites; site SE had a higher proportion of herbaceous vegetation and a lower proportion of trees.

In 1986, with the exception of site SW, the dominant vegetation type was trees-forest (T) with a maximum relative frequency value of 53 percent at site SE. Only at site SW did herbaceous vegetation (H) dominate

with a relative frequency of 47 percent. The vegetation at sites NW and NE was similar in 1986.

The vegetation at each site significantly changed from 1978 to 1986. The universal trend was a reduction in the relative frequency of herbaceous vegetation and an increase in the relative frequency of woody vegetation. The greatest change in vegetation between 1978 and 1986 was at site SE where the relative frequency of trees increased more than 47 percent. There, the trees are virtually all the exotic pest plant *melaleuca*. All other vegetation types declined during that period of time.

The exotic pest plant *Melaleuca quinquenervia* was nonuniformly present throughout the study area in 1978. This species expanded its distribution and density between 1978 and 1986, with the greatest increases occurring at site SE where it forms extensive stands and the least at site SW where it is present as small stands and scattered individuals (most of which are not yet mature).

Insufficient time passed between the start of well-field operation (May 1983) and when the photographs were taken (January 1986) to reveal any detectable changes on the photographs that could be attributed conclusively to operation of the well field. Vegetational differences not visible on the aerial photographs, but readily apparent onsite, do exist and point to future trends. Aquatic herbaceous vegetation is uncommon at site SE. Dominant herbaceous species growing there are of a wetland-upland transition. Dead sawgrass plants there and in the eastern part of site SW indicate the previous communities were wetland types. Native shrub species, particularly *Myrica cerifera*, are thriving in the herbaceous communities at site SE and also indicate a shortening in hydroperiod there.

There are some indications that the spread of *melaleuca* through the area near the well field may be influenced (positively in some areas and negatively in other areas) by the well-field operation. However, the general spread of this exotic tree throughout The Everglades makes the accurate assessment of the effect of the well-field operation impossible after only a few years of operation.

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